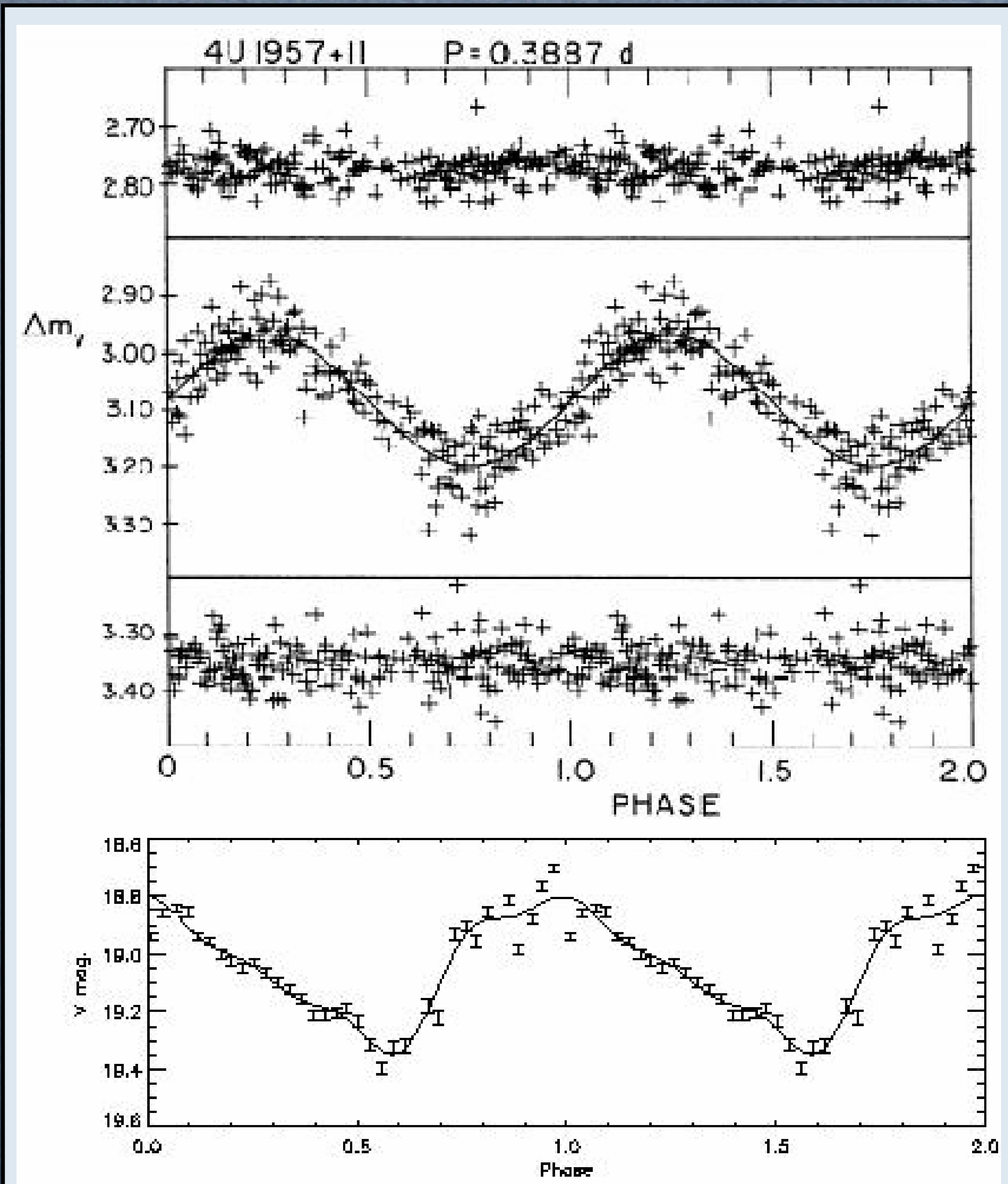
4U 1957+11:

The Most Rapidly Spinning Black Hole in the Galaxy?

Michael Nowak (MIT-Kavli Institute)
-with-
Jörn Wilms (Bamberg), Katja Pottschmidt (UMBC & GSFC),
Norbert Schulz (MIT-Kavli), Dipankar Maitra (U. Michigan),
Jon Miller (U. Michigan)

BACKGROUND:

- Low Mass X-ray Binary (9.3 hr Period)
- *Persistent* Soft (Disk Dominated) State
  - Quenched Jet: < 11.4 μJy (3 sigma)
  - 300–800X Lower than Hard State Correlation (Russell et al. 2011, ApJL)
- Low Neutral Column: 1–2 X 10^{21} cm^{-2} , Ne IX Absorption from Warm ISM
  - Distance > 5 kpc — In Galactic Halo



- Complex Lightcurve
- Periodicity has been:
  - Absent
  - ±10% Sinusoidal
  - ±30% Complex
- Highly Inclined; Optical disk partially occulted?

i ~ 75°

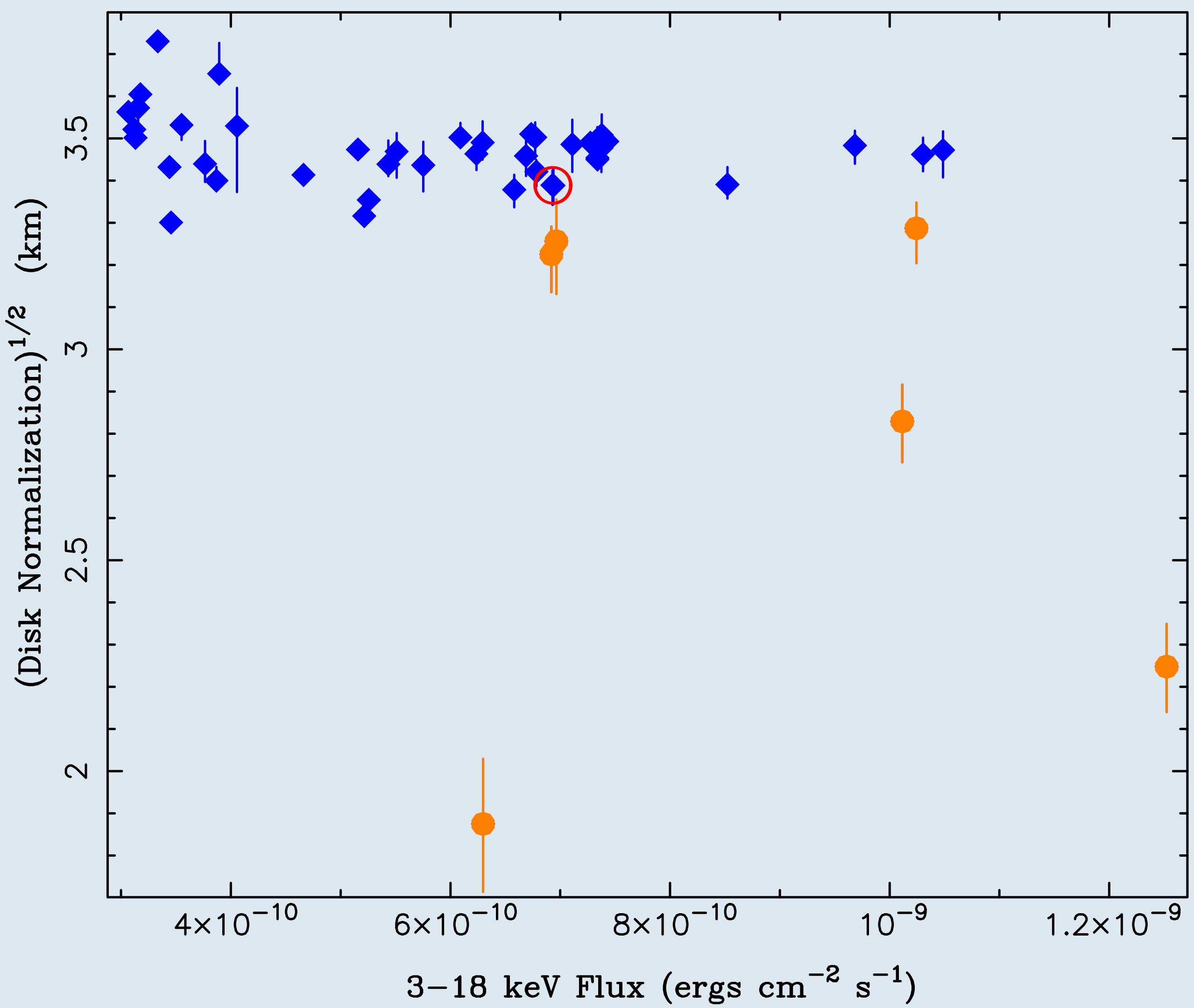
(Hakala et al. 1999)

(Bayless et al. 2011: i ~ 20–70°)

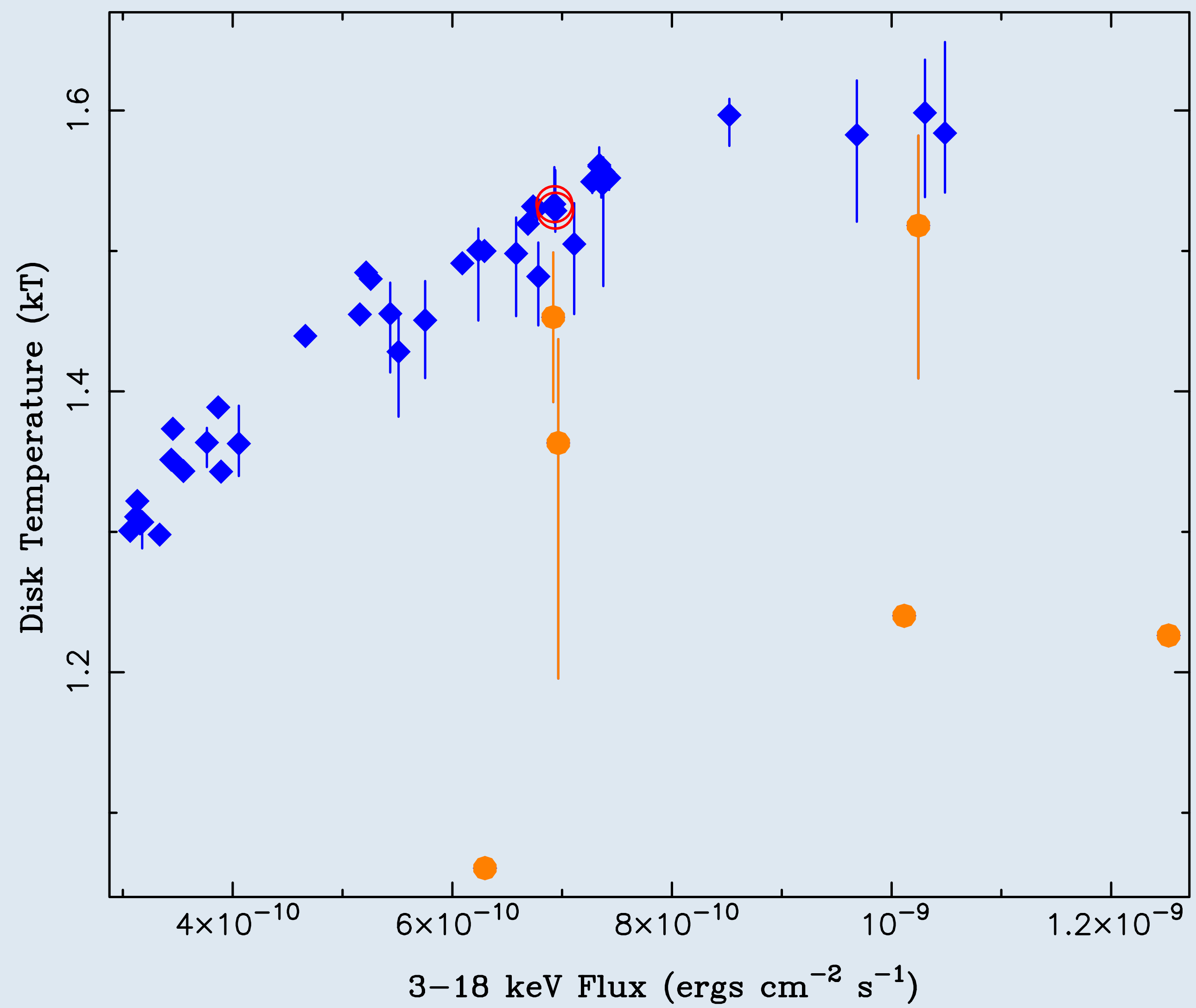
BACKGROUND:

- Unknown Mass & Distance; only limits for the inclination
  - Nominally *bad* for spin measurements, but ...
- High Disk Temperature: 1.3–1.6 keV
- Low Disk Normalization

Disk Radius



Disk Temperature



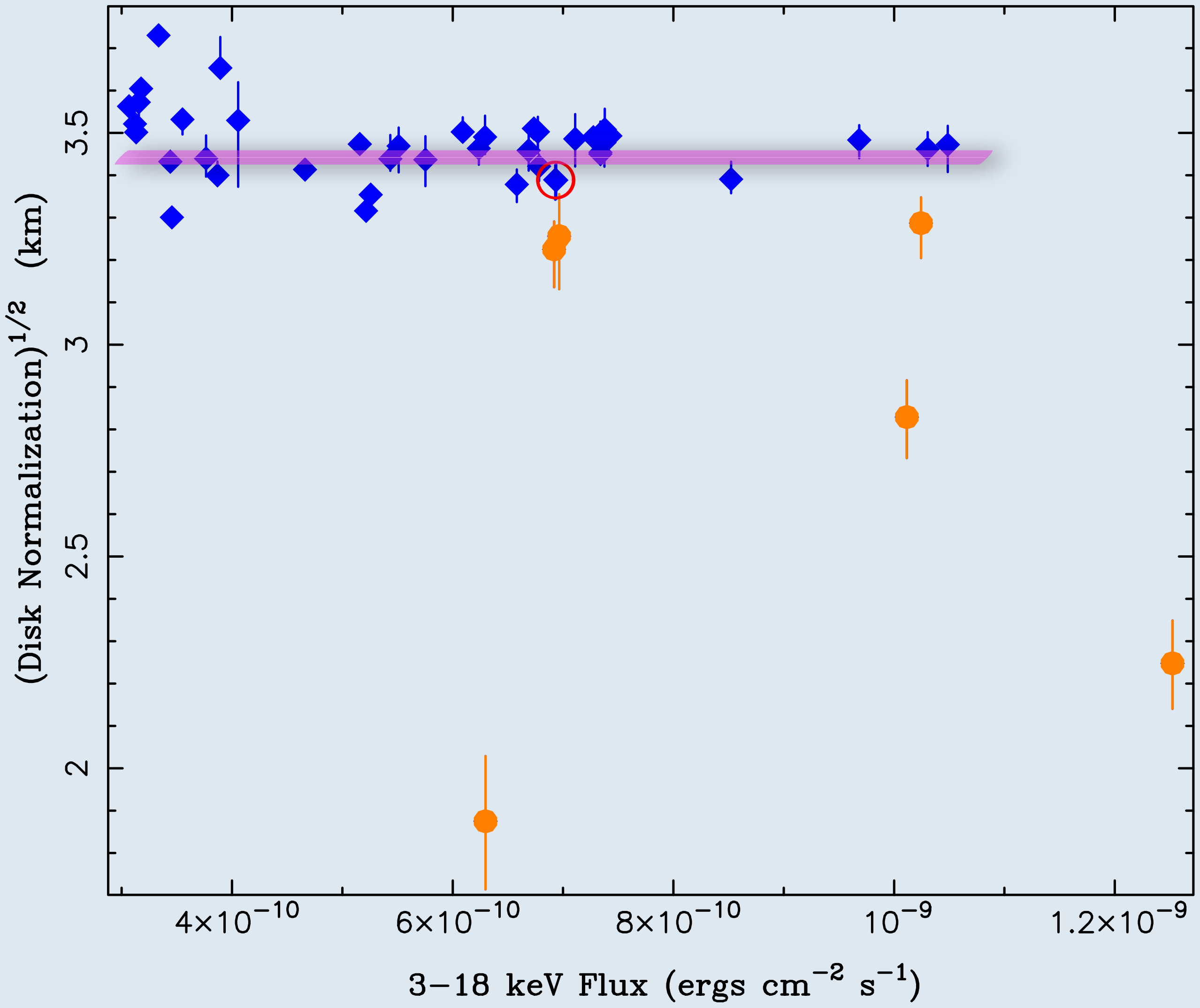
RXTE: Disk + Comptonization Fits

(Nowak et al. 2008)

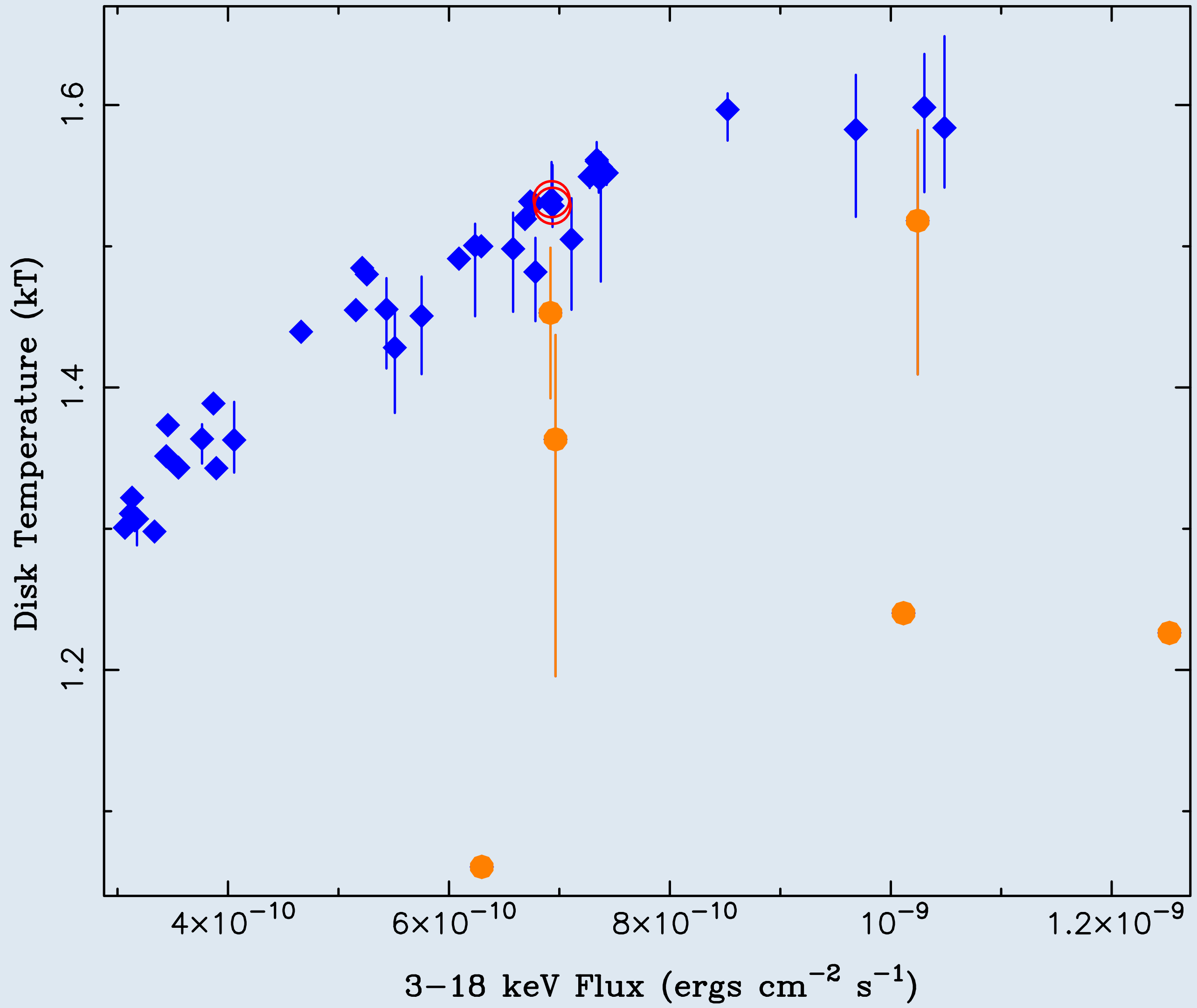
DISKS: TWO PARAMETERS

$$\frac{R^2 \cos i}{D^2}, \quad kT^4_{max}$$

Disk Radius



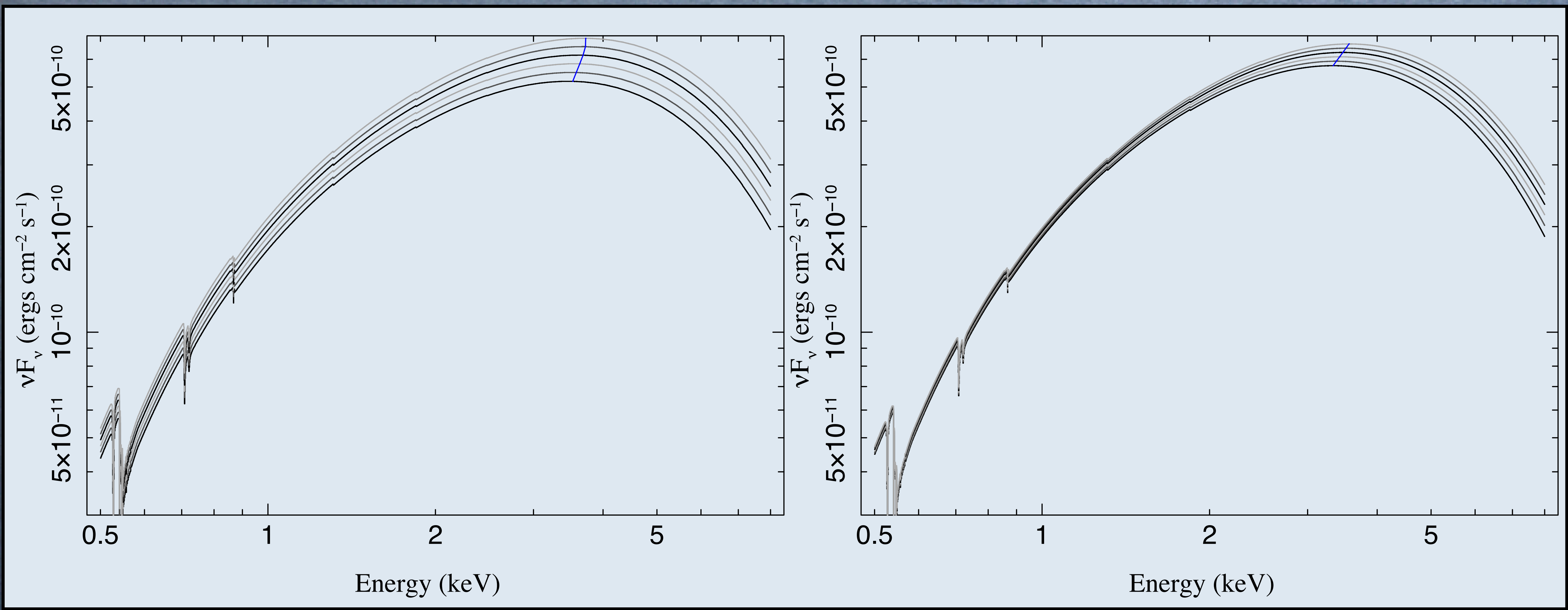
Disk Temperature



RXTE: Disk + Comptonization Fits

(Nowak et al. 2008)

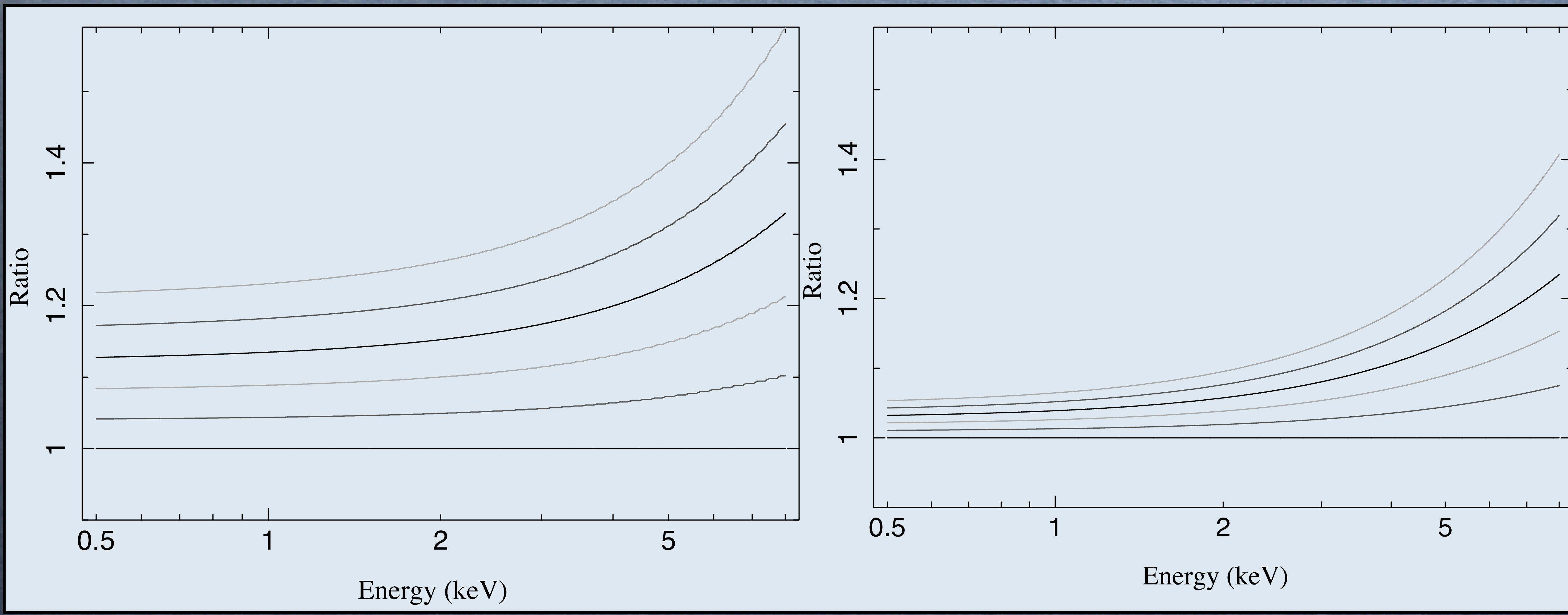
HOW MIGHT A DISK CHANGE?



Accretion Rate

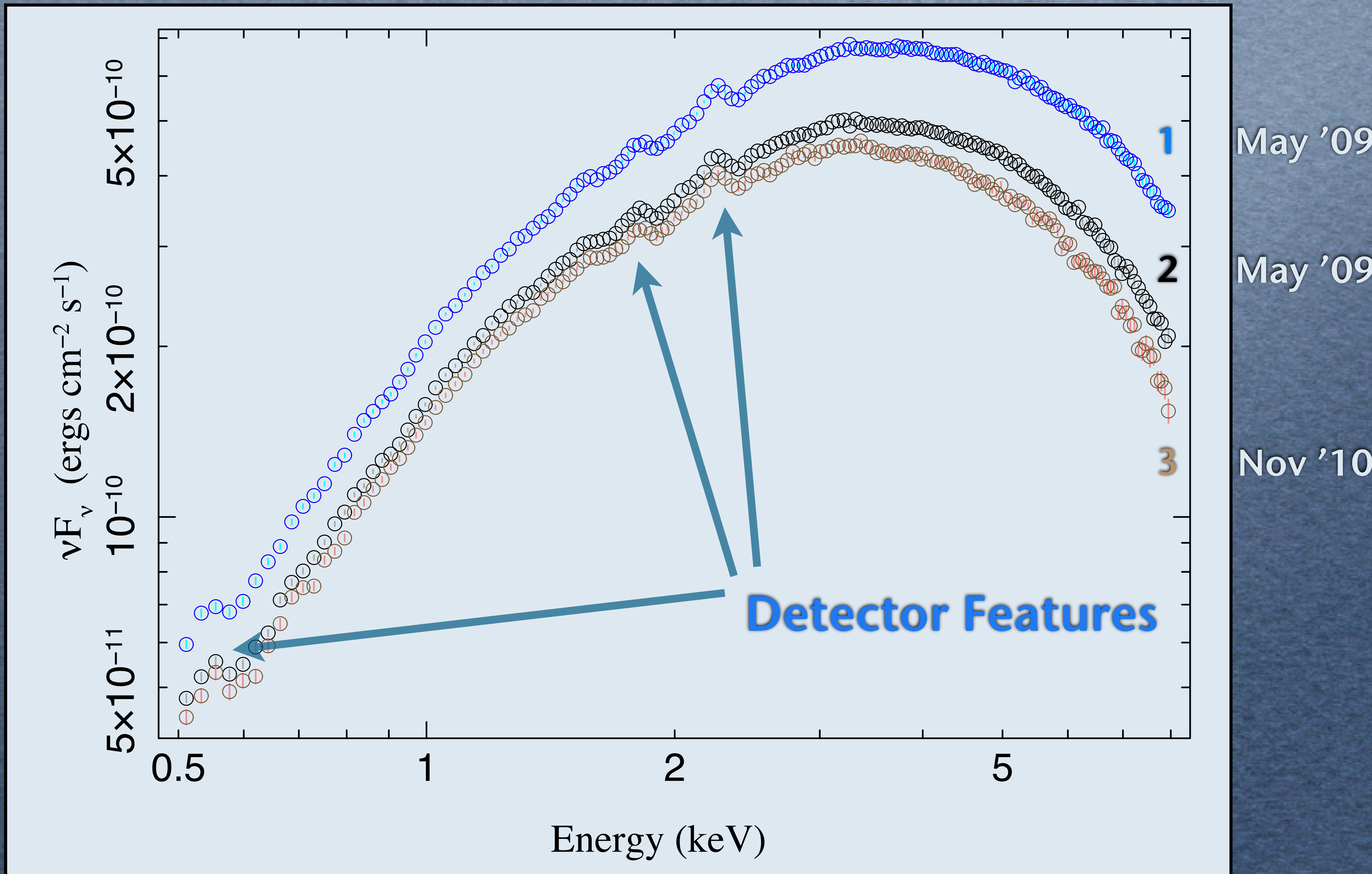
"ADAF" Like

DISTINCT IN SUZAKU BAND:

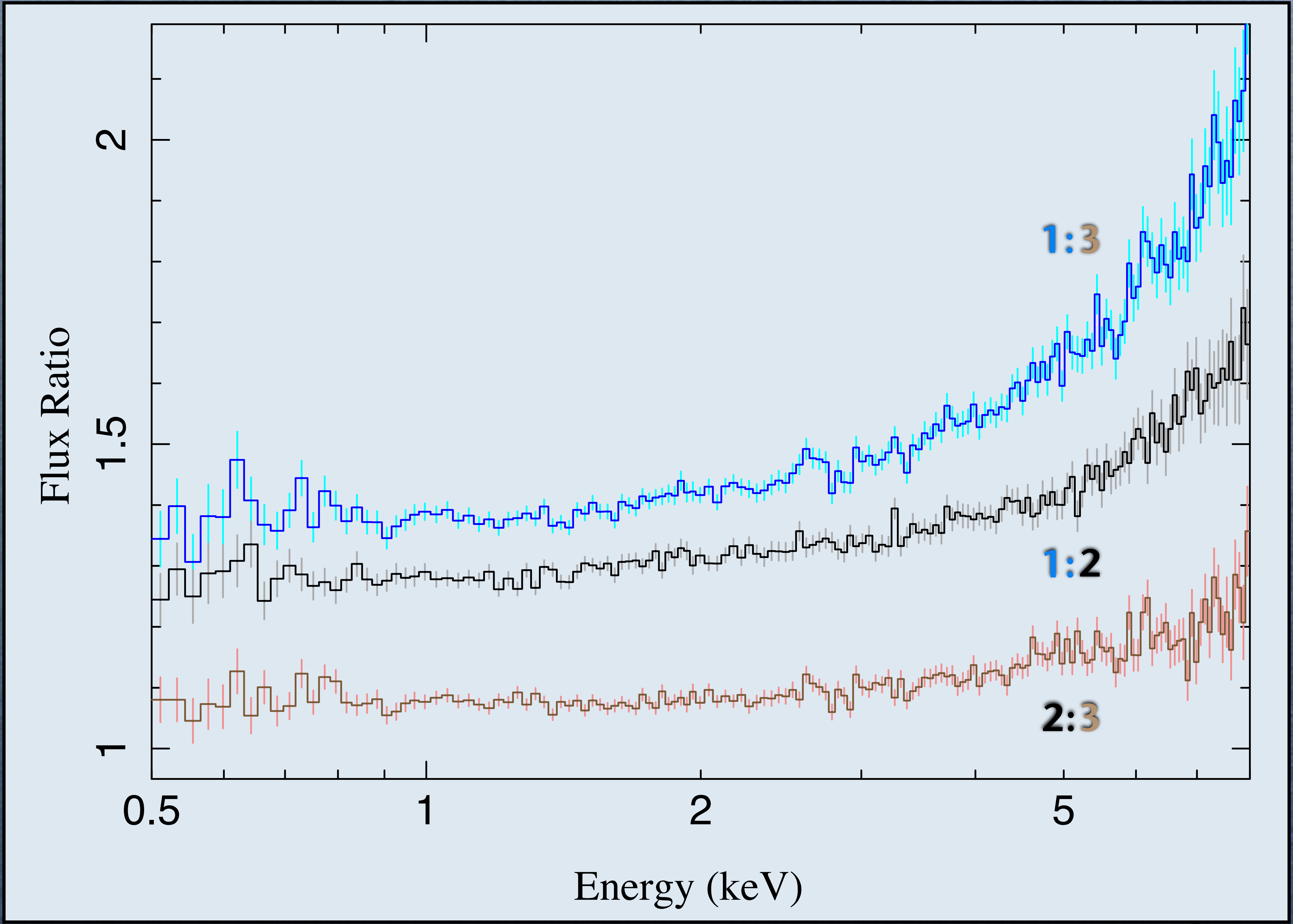


Accretion Rate

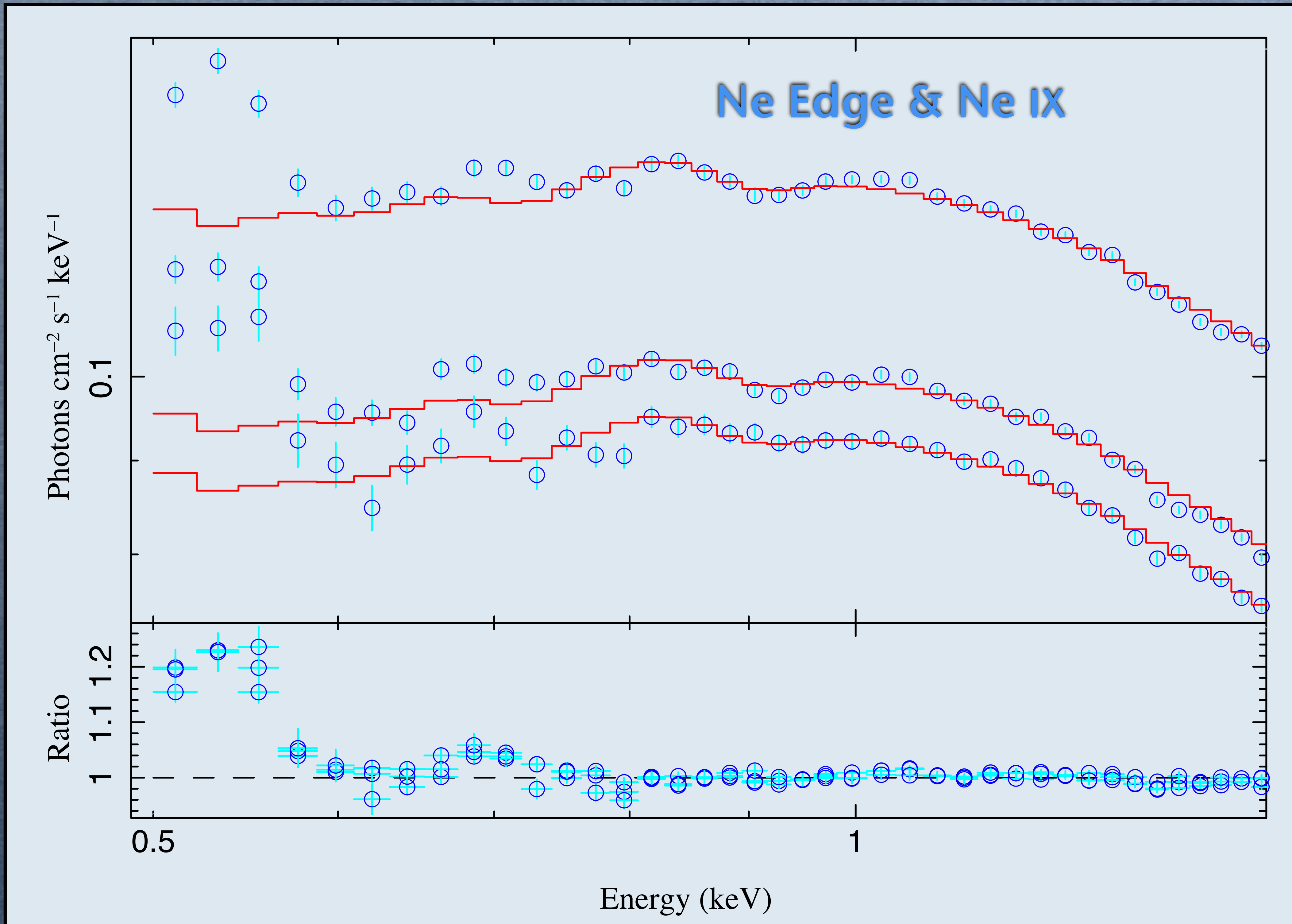
"ADAF" Like



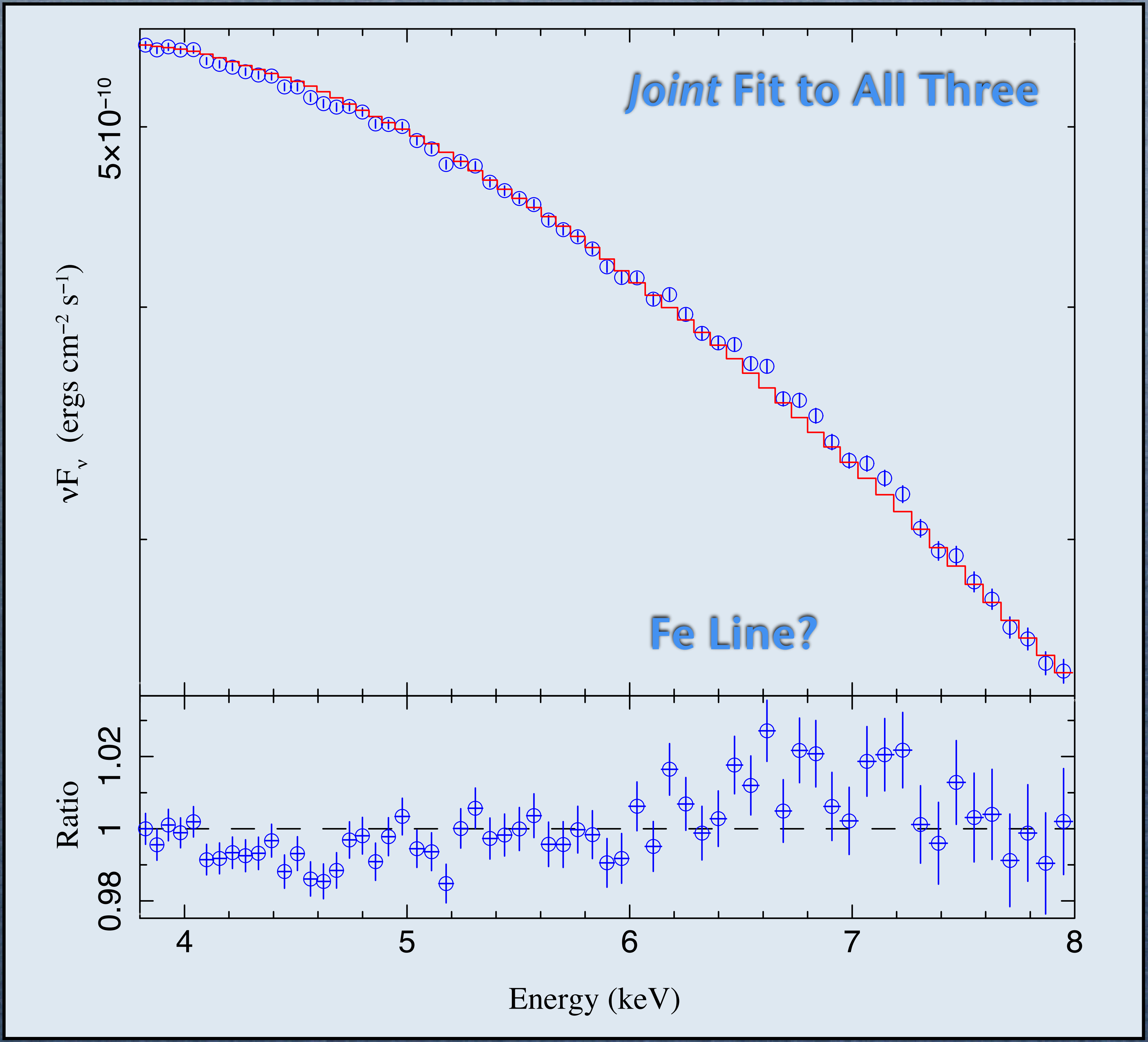
(Nowak et al. 2011)



(Nowak et al. 2011)



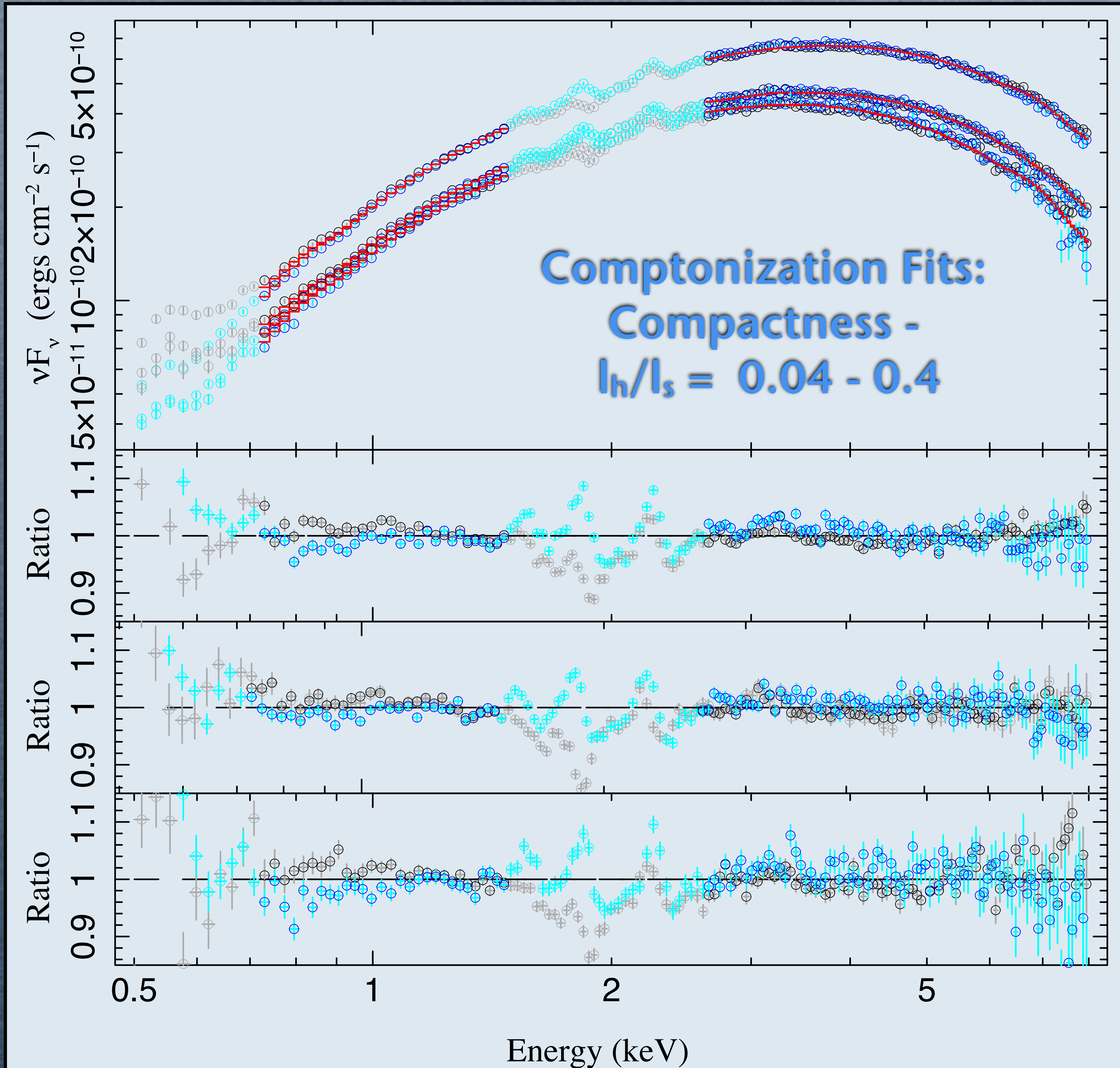
(Nowak et al. 2011)



Joint Fit to All Three
Fe Line?
5×10⁻¹⁰
νFν (ergs cm⁻² s⁻¹)
Ratio
1.02
1
0.98
4
5
6
7
8
Energy (keV)

JOINT SPECTRAL FITS:

- I. Comptonization (*eqpair*):
  - Common column & disk normalization
  - Different corona & disk kT
- II. Spinning black hole (*kerrbb*):
  - Common mass, spin, distance, column, & color correction ($T_{app}/T_{eff} \sim 1.7$)
  - Different accretion rates
  - "Fudged" hard tail (*simpl* - mimics aspects of *optically thin* Compton)



Comptonization Fits:
Compactness -
l_h/l_s = 0.04 - 0.4
νF_ν (ergs cm^-2 s^-1)
5×10^-11
10^-10
2×10^-10
5×10^-10
Ratio
0.9
1
1.15
1.1
0.5
1
2
5
Energy (keV)

- Comptonization Normalization:

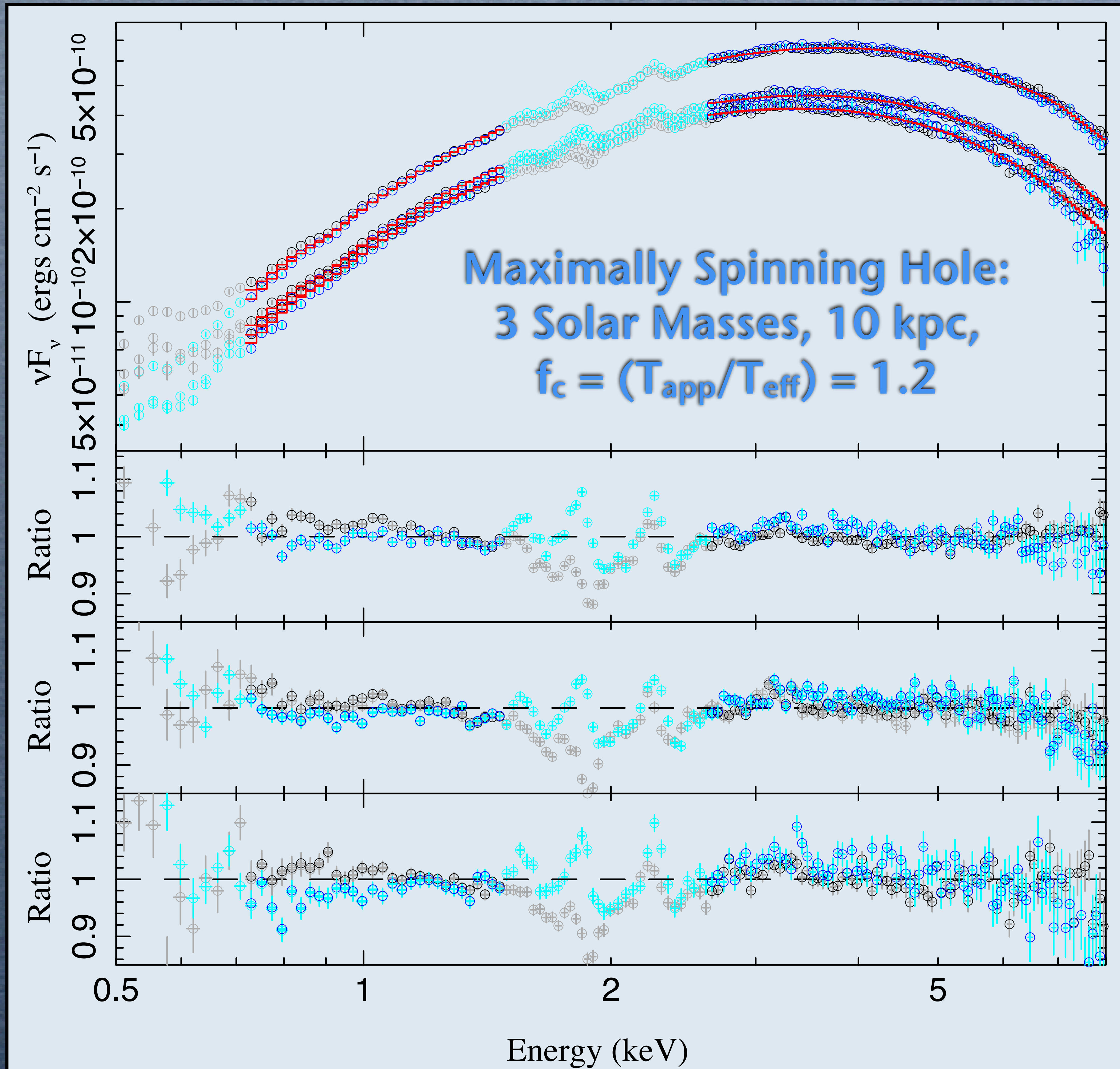
$$\boxed{\frac{(M/M_\odot)^2 \cos i}{(D/\mathrm{kpc})^2 f_c^4} = 0.003\,\frac{(M/3\,M_\odot)^2 \cos(i/75^\circ)}{(D/10\,\mathrm{kpc})^2 (f_c/1.7)^4}}$$

- *Measure* only 0.0002
- Increase the Distance to 40 kpc.
- Decrease the radius of peak emission to ~2.5 GM/c^2 (i.e., a Kerr black hole).
- Increase the color-correction factor to 3.3.

$$y \equiv \frac{4kT}{511\,\mathrm{keV}}\tau^2 \approx f_c = 3.3$$

$$\tau \approx 9.8 \left(\frac{4\,\mathrm{keV}}{kT}\right)^{1/2} \left(\frac{f_c}{3}\right)^{1/2}$$

- Optical depths of order 10?
- Relatively unexplored Comptonization regime



Maximally Spinning Hole:
3 Solar Masses, 10 kpc,
$f_c = (T_{app}/T_{eff}) = 1.2$
νF_ν (ergs cm^{-2} s^{-1})
5×10^{-10}
2×10^{-10}
10^{-10}
5×10^{-11}
Ratio
1.15
1.1
1
0.9
0.5
2
5
Energy (keV)

DISK SPIN MODEL SCALING:

- If L/L_{Edd} fixed (faintest $\gtrsim$ low state transition):

$$\boxed{\left(\frac{T_{\rm app}}{f_c}\right)^4 \propto \frac{(L/L_{\rm Edd})\cdot M}{R^2} \propto \frac{(L/L_{\rm Edd})}{M}}$$

- T_{app} is fixed by observation:

$$\boxed{M \propto {f_c}^4}$$

- L/L_{Edd} is fixed by assumption:

$$\boxed{\frac{\dot{M}}{M} \propto \text{constant} \Rightarrow \dot{M} \propto {f_c}^4}$$

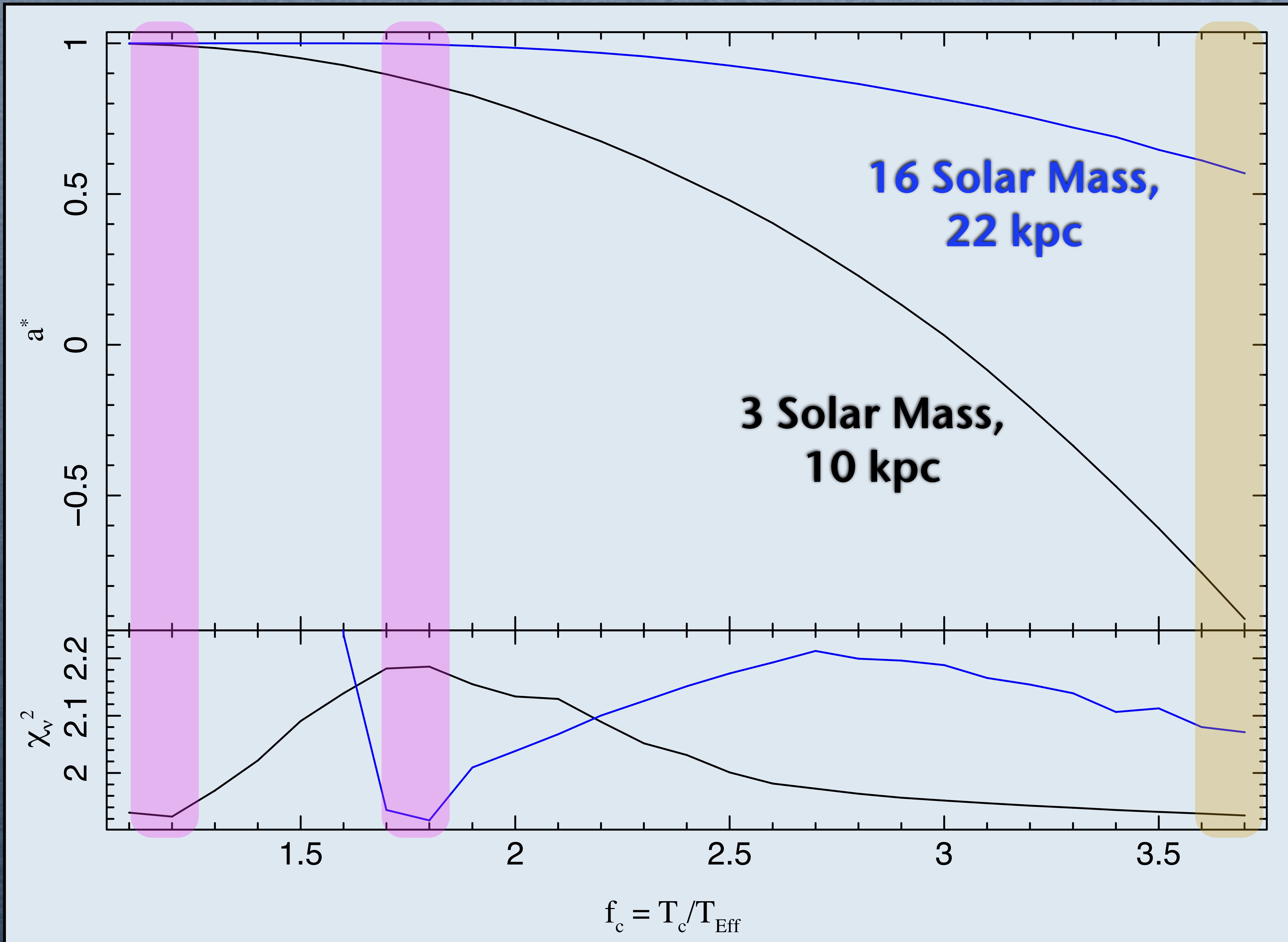
- Flux is fixed by observation:

$$\boxed{\frac{M^2}{D^2 f_c^4} \propto \frac{f_c^8}{D^2 f_c^4} \propto \text{constant} \Rightarrow D \propto {f_c}^2}$$

3 Solar Mass, 10 kpc, f_c~1.2

$\Downarrow$

16 Solar Mass, 22 kpc, f_c~1.7



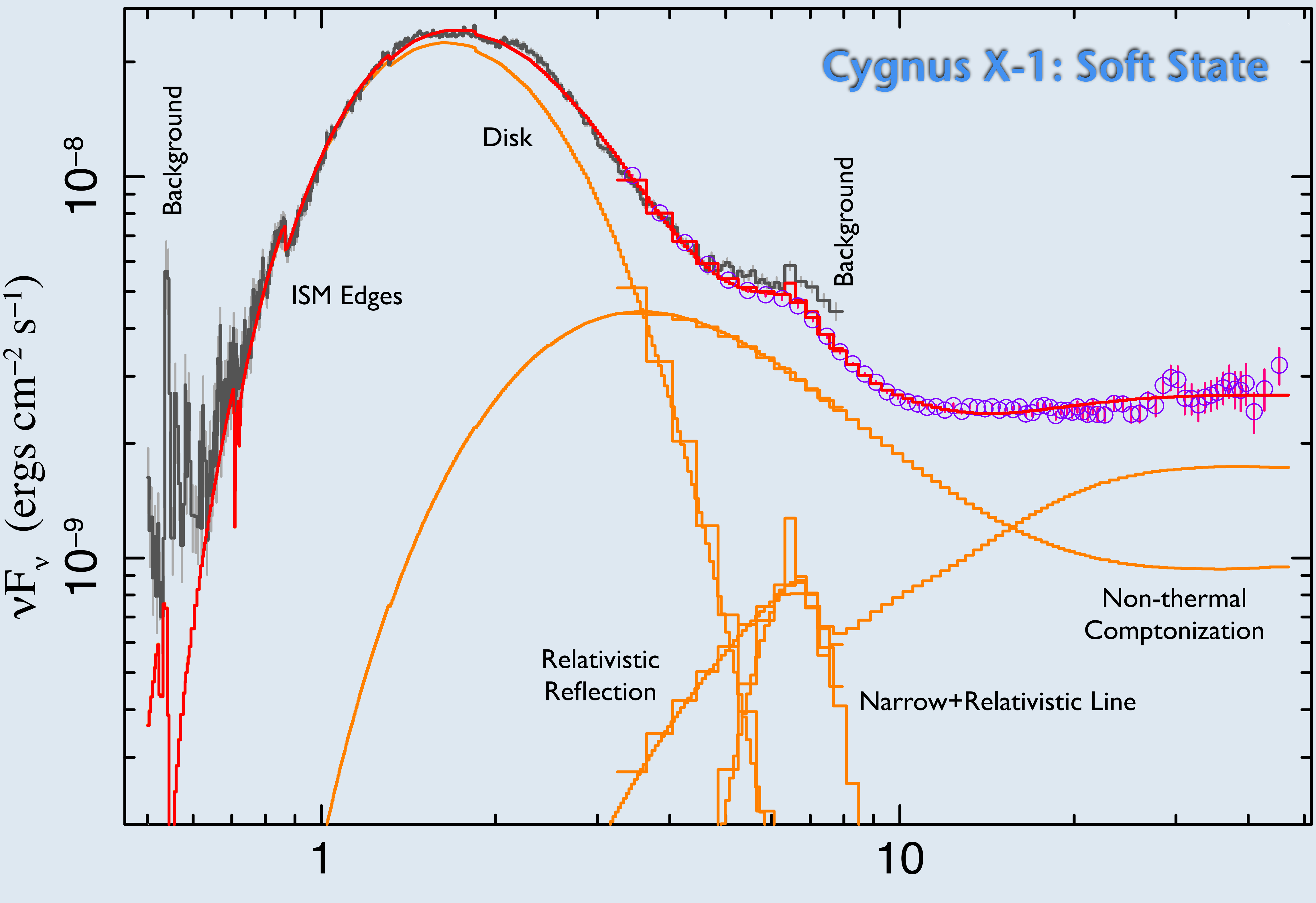
16 Solar Mass,
22 kpc
3 Solar Mass,
10 kpc
a*
1
0.5
0
−0.5
χ_ν^2
2.2
2.1
2
1.5
2
2.5
3
3.5
$f_c = T_c/T_{Eff}$

CONCLUSIONS:

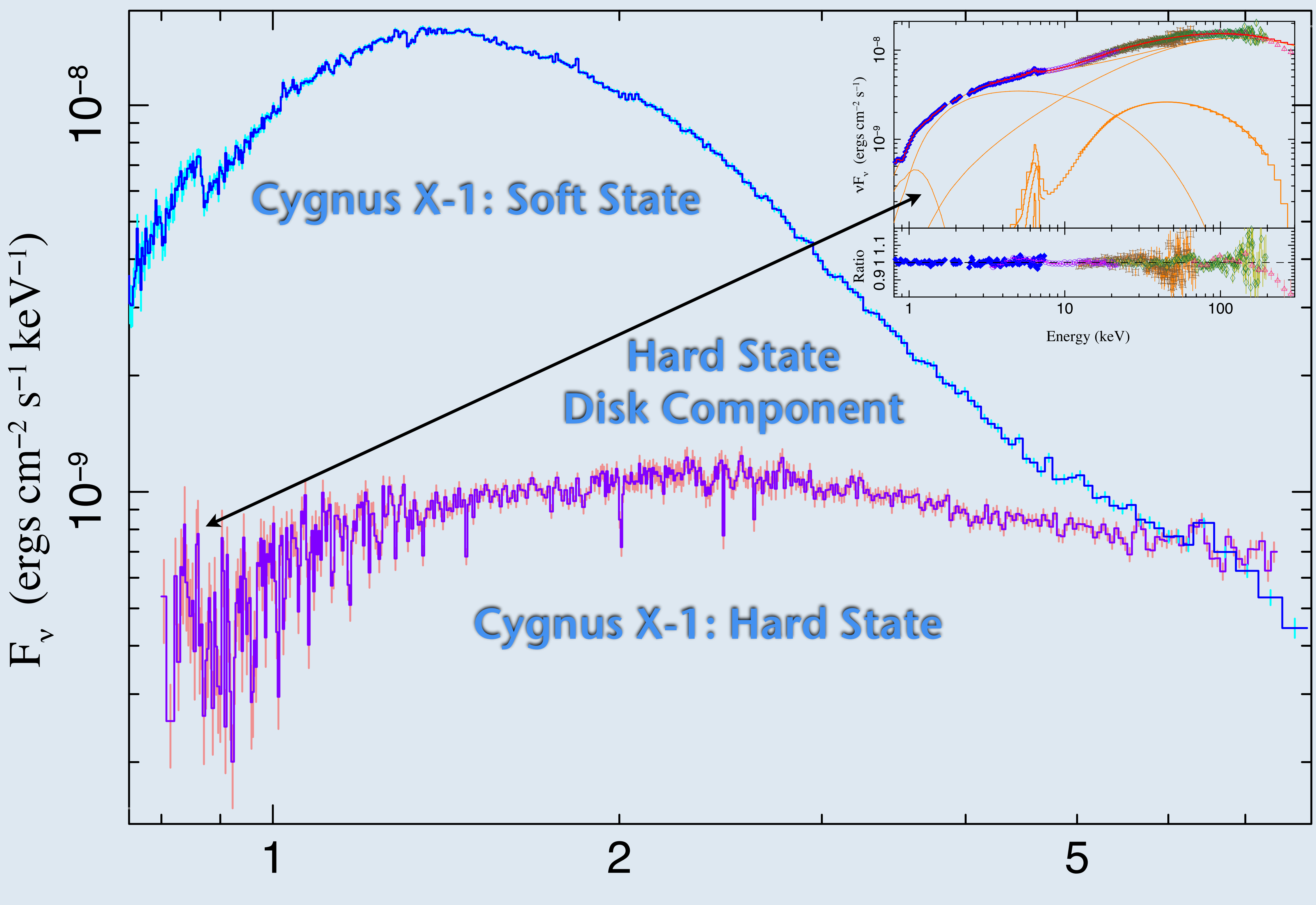
- Could be low mass, high L/L_{Edd}, at large distance (~40 kpc)
    - But why so little X-ray variability?
- High kT & Low Normalization is Consistent with Rapid Spin
- High Spin can be avoided with large color-correction factors
    - Low kT, High Optical Depth Corona
    - But why such stable properties?

ADDENDA: QUESTION RESPONSE

- Is Cyg X-1 rapidly spinning?
- Soft state - disk dominates, but normalization is *lower than expected*
  - Low norm driven by new low distance (Reid et al. 2011), & new high mass estimate (Orosz et al. 2011)
- Similar story as 4U 1957+11
  - Consistent with High Spin (Gou et al. 2011)
  - ... or it must have a color correction factor ~> 3 (high optical depth, low kT corona?)



arXiv:1107.2391



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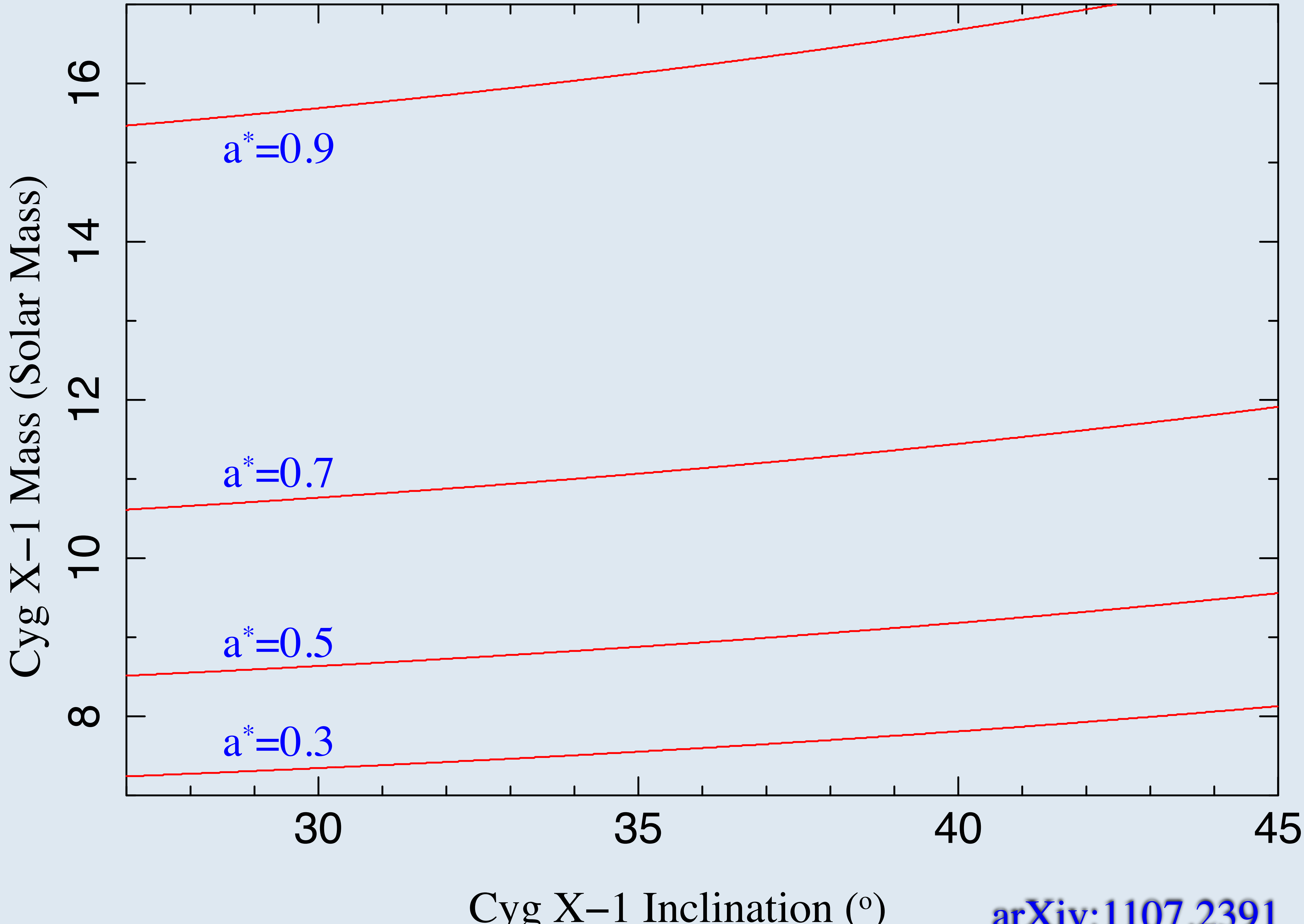

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